

ANALYSIS

Decomposition of factors determining the trend of CO₂ emissions from car travel in Great Britain (1970–2000)

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Abstract

Carbon dioxide (CO₂) is the most important of the greenhouse gases that are causing global warming. The transport sector currently accounts for more than one-quarter of CO₂ emissions and more importantly its share in total emissions is increasing in most countries. This paper investigates the key factors in the change in CO₂ emissions from car travel in Great Britain over the last 30 years. It attempts to disentangle determinants of growth in CO₂ emissions from car travel, which has the largest share of emissions in road transport. The study is based on various decomposition analyses, starting from the IPAT identity. As summarised in the IPAT identity, the degree of the *Impact* of human activity on the environment is determined by changes in *Population*, *Affluence* (per-capita consumption) and *Technology* (environmental impact per quantity of consumption). In the case of CO₂ emissions from car travel in Great Britain, the affluence (*A*) factor (car driving distance per person) was a dominant force for the growth of emissions over the last 30 years. Not only do people travel longer distances by cars than 30 years ago, but car occupancy rates have also decreased, contributing to the growth of car driving distance per person. Although technology (*T*) factors such as fuel efficiency and fuel substitution to diesel fuel partly cancelled out these growth effects of affluence factors, this contribution was relatively small. However, in the 1990s there emerged a different pattern in the trend. Of the affluence (*A*) factors, the growth rate of car trip distance per person weakened considerably. As for the technology (*T*) effect, the carbon intensity of car driving kept decreasing over this period. Therefore, although CO₂ emissions from car travel (*I*) continued to increase, the growth rate became substantially lower than in the earlier periods. More detailed investigation into the determinants of both affluence (*A*) factors and technology (*T*) factors is needed to confirm whether the trend in the 1990s indicates that carbon dioxide emission from car travel in Great Britain reached the turning point of the Environmental Kuznets Curve.

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1. Introduction

Emissions of carbon dioxide (CO₂), the main greenhouse gas, fell by 20% between 1970 and 2000 in the UK. However, emissions from road transport rose by 93% during the same period. Road transport currently account for 21% of total carbon dioxide emission in the UK¹ (Fig. 1). Thus, road transport is one of the key sectors in which policy change is needed to meet the reduction target for CO₂ emissions set under the Kyoto Protocol². This study concerns the growing emissions of CO₂ from road transport, in particular CO₂ emissions from car travel, which has the largest share of emissions in road transport. More specifically, this study investigates the key driving forces for the trend of CO₂ emissions from car travel in Great Britain over the past 30 years (1970–2000).

This study breaks down the emission trend into several compositional factors on the basis of various decomposition equations. The key purposes of using decomposition equations are as follows. First, it is possible to identify the driving forces of the past changes in an aggregate indicator by investigating the changes in each individual compositional factor. Secondly, it may be more feasible to indirectly forecast an aggregate indicator by first forecasting each individual compositional factor rather than to forecast the aggregate indicator itself. Thirdly, this approach will be useful in finding effective leverage points for a policy intervention to change an aggregate indicator. This paper will focus on past trends analysis and subsequent studies will be followed to address forecast of future changes and policy implication.

In the next section, various decomposition equations will be presented to investigate the driving forces behind the changes in CO₂ emissions from car travel. First, the IPAT identity, which breaks down the determinants of changes in environmental impacts (*I*) into population (*P*), affluence (*A*) and technology (*T*) will be introduced. This will be followed by a more detailed decomposition of affluence (*A*) and technology (*T*) factors, respectively. Section 3 then presents

the results of the decomposition analysis of CO₂ emissions from car travel in Great Britain over the last 30 years on the basis of various decomposition equations suggested in Section 2. Finally, the key results of the analysis in this paper are summarised in the Conclusion.

2. Decomposition equations of CO₂ emissions from car travel

2.1. The IPAT identity

Ehrlich and Ehrlich (1990) suggested a simple identity equation summarising the relationship between the growth of human society and its environmental consequence.³

$$\text{Impact} = \text{Population} \times \text{Affluence} \times \text{Technology}$$

As summed up in the above equation, which was often referred as the IPAT identity, the impact of human activity on the environment can be viewed as the product of three different factors; the population, per-capita consumption, which is determined by affluence and the environmental impact per quantity of consumption, which is determined by technology. The total impact of a society can be lowered by decreasing any of these three factors, as long as the others does not increase so as to offset the reduction.

The IPAT identity summarises a general relation between human behaviour and its environmental impact. However, it can also be applied to a specific environmental issue. For example, *I* represents an aggregate environmental indicator such as the amount of CO₂ emission. *P* denotes population or other 'scale factors'. *A* corresponds to a specific behaviour or consumption per capita which is a cause for the environmental impact represented by *I*. *T* stands for environmental impact per unit of the consumption or behaviour represented by *A*.

Although the IPAT formula may be a simple identity equation, it can be a useful starting point to track down determinants of past change in an aggregate environmental indicator, to forecast its

¹ Data source: DEFRA (2002).

² Under the Kyoto Protocol, the UK has a legally binding target to reduce emissions of the basket of six greenhouse gases by 12.5% relative to 1990 level over the period 2008–2012. It also has a domestic goal to cut CO₂ emissions by 20% below 1990 levels by 2010 (Department of Environment Transport and Region, 2000).

³ According to Ekins (2000), this equation originally appeared in Ehrlich and Holdren (1971), Commoner (1971) and Holdren and Ehrlich (1974) in slightly different forms.

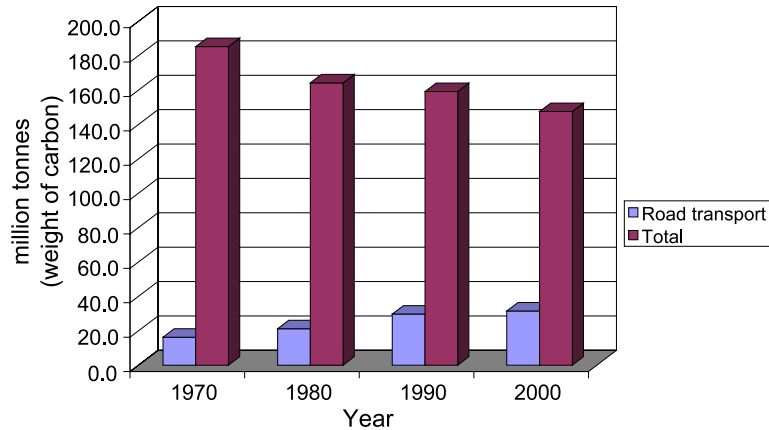


Fig. 1. CO₂ emission from road transport in the UK.

future change and finally to find effective leverage points for policy intervention to control it. Dietz and Rosa (1994), Stern et al. (1997), Turner II (1997), Angel et al. (1998), Rosa and Dietz (1998), Ekins (2000), Diesendorf (2002), Roca (2002), Schulze (2002), and York et al. (2002, 2003) provide various discussions on the IPAT identity. Also, there have been numerous empirical studies which uses the IPAT formula or its various modified forms to decompose driving forces of an environmental impact indicator (e.g. Commoner, 1990; Harrison, 1993; Bongaarts, 1992; Stern et al., 1992; Dietz and Rosa, 1997; Shi, 2003).⁴

In addition, International Energy Agency (IEA) developed the ASIF equation by expanding the IPAT identity, where *A* stands for activity (e.g. travel activity), *S* for structure (e.g. modal share), *I* for energy intensity and *F* for fuel mix (Schipper et al., 2001a,b). The Kaya identity suggested by Intergovernmental Panel on Climate Change (IPCC) is also a specific application of the IPAT formula (Nakićenović et al., 2000). It multiplies population growth, per capita value added, energy consumption per value added, and emissions per unit of energy on one side of

the identity to produce total CO₂ emissions on the other side (Kaya, 1990; Yamaji et al., 1991).⁵

The IPAT identity also provide a primary accounting framework in this study to investigate driving forces of CO₂ emissions trend from car travel in Great Britain. In particular, this study uses various decomposition equations at difference levels of analysis, starting from the IPAT identity.

2.2. Application of the IPAT identity into CO₂ emissions from car travel

The amount of carbon dioxide emission from car travel can be represented by an *I=PAT* type decomposition equation like Eq. (1)

$$C = P(D/P)(C/D) \quad (1)$$

where *C* stands for the amount of CO₂ emission, *P* for population, *D* for total car driving distance (vehicle km). Thus, *D/P* is car driving distance per person and *C/D* is the carbon intensity of car driving. It can be said that *C* represents environmental Impact in *I=PAT* equation, *P* represents Population, *D/P* represents Affluence and *C/D* represents Technology. To reduce CO₂ emission from car travel, we need to reduce at least one of the factors in the right side of Eq. (1).

By transforming Eq. (1) into a log form and differentiating, we obtain:

$$\frac{1}{C} \frac{dC}{dt} = \frac{1}{P} \frac{dP}{dt} + \frac{P}{D} \frac{d(D/P)}{dt} + \frac{D}{C} \frac{d(C/D)}{dt} \quad (2)$$

⁴ Among these studies, Dietz and Rosa (1997) and Shi (2003) are quite different from other studies in that they use the IPAT equation as a regression model rather than an identity equation. This approach is known as Stochastic Impact by Regression on Population, Affluence, and Technology (STIRPAT) (Dietz and Rosa, 1994). The key difference of this approach is that they use an independent measure of *T* in IPAT equation rather than solving for *T* as *I/PA* (Dietz and Rosa, 1997; York et al. 2003).

⁵ Quoted from Nakićenović et al. (2000).

Eq. (2) shows that percentage change rate in CO₂ emissions at a certain time point can be represented by the sum of the change rates in population, car driving distance per person and CO₂ emission per car driving distance. However, to quantify the relative contribution of each term on the right hand in Eq. (1) on the emission trend, attention should be paid to the change of each variable over a specific time period rather than the instant change rate. In fact, the index of CO₂ emissions between year 0 and year T can be represented by the product of the index of population, car driving distance per person and CO₂ emission per car driving distance as Eq. (3). That is, the determinants of changes in CO₂ emissions from car travel between year 0 and year T can be first identified by investigating changes in these three compositional factors over the period.

$$\frac{C_T}{C_0} = \frac{P_T}{P_0} \frac{(D/P)_T}{(D/P)_0} \frac{(C/D)_T}{(C/D)_0} \quad (3)$$

2.3. Compositional factors determining per capita car driving distance

As explained by Eqs. (1)–(3), the compositional factors determining the amount of CO₂ emissions from cars travel can be classified into population, car driving distance per capita (affluence factor) and CO₂ emission per car driving distance (technology factor). This paper further breaks down the compositional factors determining car driving distance per capita and CO₂ efficiency of car driving. This section focuses on the affluence (A) factor and the following section will address the technology (T) factor.

The compositional factors determining per capita car driving distance (D/P) can be represented by Eq. (4)

$$\frac{D}{P} = \left(\frac{T_c}{P} \right) \left(\frac{D}{T_c} \right) \quad (4)$$

where T_c/P represents car trip distance per person (km) and D/T_c represents the ratio of vehicle km to car passenger km, which is equivalent to the reciprocal of occupancy rate. Per capita car driving distance can change by altering either of these compositional factors.

Similarly to Eq. (3), a decomposition of index is useful to quantify the relative contribution of each

term on the right hand in Eq. (4) on the trend of car driving distance per person. The index of car driving distance per person between year 0 and year T can be represented by the product of the index of car trip distance per person and (reciprocal of) occupancy rate between year 0 and year T (Eq. (5)).

$$\frac{(D/P)_T}{(D/P)_0} = \frac{(T_c/P)_T}{(T_c/P)_0} \frac{(D/T_c)_T}{(D/T_c)_0} \quad (5)$$

In addition, T_c/P in Eq. (4) can be further broken down into T/P and T_c/T as Eq. (6), where T/P stands for total trip distance per person by all modes and T_c/T for the share of car trips in total trip distance. This will be useful to investigate how change in car trip distance is related to change in overall trip distance per person by all modes. Similarly to Eq. (5), the index of driving distance per person between year 0 and year T can be represented by the product of the index of individual compositional factors of Eq. (6) between year 0 and year T .

$$\frac{D}{P} = \left(\frac{T}{P} \right) \left(\frac{T_c}{T} \right) \left(\frac{D}{T_c} \right) \quad (6)$$

An alternative approach to disentangle the determinants of changes in car driving distance per person (D/P) is to focus on changes in per capita vehicle (S/P) and average driving distance per vehicle (D/S) as Eq. (7).

$$\frac{D}{P} = \left(\frac{S}{P} \right) \left(\frac{D}{S} \right) \quad (7)$$

where S stand for the number of vehicle stock.

It must be noted that while Eqs. (4) and (6) concerns travel behaviour of people, the focus of Eq. (7) was shifted to the use of vehicles.

2.4. Compositional factors determining CO₂ efficiency of car driving

The compositional factors determining the CO₂ efficiency (or intensity⁶) of car driving (technology

⁶ To be exact, 'CO₂ intensity' means carbon dioxide emission per driving distance (C/D) and 'CO₂ efficiency' is equivalent to the reciprocal of CO₂ intensity, that is, car driving distance per unit of CO₂ emission. However, the two terminologies will be used interchangeably in this study unless it causes confusion in the meaning. A similar relationship exists regarding 'fuel efficiency' and 'fuel intensity'.

factor) can be broken down as in Eq. (8). Since no end-of-pipe technology of reducing CO₂ emissions is currently available, the technology (*T*) factor mainly concerns fuel efficiency and fuel substitution.

$$\frac{C}{D} = \sum_i \left(\frac{D_i}{D} \frac{F_i}{D_i} \frac{C_i}{F_i} \right) \quad (8)$$

Here D_i/D denotes the share of vehicle with fuel type *i* in total vehicles km, F_i/D_i denotes average fuel consumption by fuel type *i* and C_i/F_i denotes CO₂ emission coefficient of fuel type *i*. The change in average CO₂ emission per car driving distance (carbon intensity, C/D) can be caused by change in fuel efficiency of vehicles (fuel intensity effect, F_i/D_i), fuel substitution to a fuel having different carbon contents (fuel structure effect, D_i/D) or change in CO₂ intensity of each fuel type (CO₂ emission factor effect, C_i/F_i).⁷

For simplicity, Eq. (8) is rewritten into Eq. (9)

$$e = \sum_i (s_i f_i c_i) \quad (9)$$

where $e=C/D$ (CO₂ efficiency of car driving), $s_i=D_i/D$ (share of fuel type *i* in total vehicle km), $f_i=F_i/D_i$ (fuel efficiency of fuel type *i*) and $c_i=C_i/F_i$ (CO₂ intensity of fuel type *i*).

Differentiating with respect to time,

$$\begin{aligned} \frac{de}{dt} = & \sum_i \left(f_i c_i \frac{ds_i}{dt} \right) + \sum_i \left(s_i c_i \frac{df_i}{dt} \right) \\ & + \sum_i \left(s_i f_i \frac{dc_i}{dt} \right) \end{aligned} \quad (10)$$

Dividing by $e=C/D$,

$$\begin{aligned} \frac{1}{e} \frac{de}{dt} = & \sum_i \left(\frac{C_i}{C} \frac{1}{s_i} \frac{ds_i}{dt} \right) + \sum_i \left(\frac{C_i}{C} \frac{1}{f_i} \frac{df_i}{dt} \right) \\ & + \sum_i \left(\frac{C_i}{C} \frac{1}{c_i} \frac{dc_i}{dt} \right) \end{aligned} \quad (11)$$

⁷ CO₂ emission factor of petrol and diesel fuel in this study is based on the figure in the UK Greenhouse gas inventory, i.e. 857 kg C/tonne for diesel and 855 kg C/tonne for petrol (quoted from http://www.aeat.co.uk/netcen/airqual/naei/annreport/annrep99/app1_29.html). CO₂ emission factor changes slightly each year when it is converted to a volumetric basis because fuel conversion factor fluctuates every year. The declared fuel conversion factor can be referred to the Digest of UK Energy Statistics (DTI).

Eq. (11) shows that change rate in CO₂ efficiency of car driving at a certain time point is equal to the sum of change rate in fuel share, fuel efficiency and CO₂ intensity of each fuel type *i* with a weight of C_i/C . However, Eq. (11) cannot be directly applied into actual data set over discrete time points. Nor is it possible to use a quantitative relationship among index of variables in Eq. (8) over a specific time period as in Eqs. (3) and (5) because fuel structure, the weighting variable, changes over time. In this case, the index decomposition method can be a very effective method to quantify the relative contribution of each compositional factor to changes in the CO₂ efficiency of car driving.

According to Ang and Liu (2001), the technique of decomposing an aggregate energy indicator to give quantitative measures of the relative contributions of a set of predefined factors leading to the changes in the aggregate indicator was first proposed in the late 1970s. A recent comprehensive methodological review of index decomposition methods is provided by Ang and Zhang (2001).

Index decomposition methods have been widely used in the literature to break down the component of changes in energy consumption. In the transport sector, Schipper et al. (1992, 1997, 2001a), Schipper (1995), Scholl et al. (1995), Kiang and Schipper (1996), and Lakshmanan and Han (1996) have used index decomposition methods to disentangle determinants of changes in energy consumption or CO₂ emissions. Whereas these studies analysed all the passenger travel or freight transport by various modes, this study only focuses on car travel. As Schipper et al. (2001a) suggested by using the ASIF equation, it is important to keep a record of the changes in activity, mode shares, energy intensity and fuel mix in all modes. However, focusing on car travel alone also has an advantage in that it allows various decomposition analyses of different levels, starting from the *I=PAT* type equation. This is expected to provide more comprehensive insights into the determinants of change in CO₂ emission from car travel.

Whereas most previous studies, which applied the index decomposition method into the transport sector, used the Laspeyres index decomposition method, this study is based on the log-mean Divisia

Index method. With the Laspeyres index decomposition method, the individual effect of each causal factor is estimated by letting only one factor change while the others are held constant over time. For example, it investigates how CO₂ emissions might have changed if only one factor, such as fuel mix or energy intensity had changed. However, one shortcoming of the Laspeyres index method is that it often has a large residual term (Ang and Zhang, 2001). The log-mean Divisia index decomposition method is said to overcome this shortcoming of the Laspeyres index decomposition method (Ang and Liu, 2001). The log-mean Divisia index method makes use of the logarithmic mean of two end point values as a weight function. It leaves no residual term after the decomposition. Ang and Liu (2001) and Ang et al. (2003) provide a detailed explanation of log-mean Divisia index decomposition method. The application of the log-mean Divisia decomposition method suggested by Ang and Liu (2001) into Eq. (11) results in the following identity equation.⁸

$$\begin{aligned} \frac{e_t}{e_0} = & \exp \left(\sum_i \frac{L(C_{i,0}/D_0, C_{i,T}/D_T)}{L(C_0/D_0, C_T/D_T)} \ln(s_{i,T}/s_{i,0}) \right) \\ & \times \exp \left(\sum_i \frac{L(C_{i,0}/D_0, C_{i,T}/D_T)}{L(C_0/D_0, C_T/D_T)} \ln(f_{i,T}/f_{i,0}) \right) \\ & \times \exp \left(\sum_i \frac{L(C_{i,0}/D_0, C_{i,T}/D_T)}{L(C_0/D_0, C_T/D_T)} \ln(c_{i,T}/c_{i,0}) \right) \end{aligned} \quad (12)$$

where $L(a,b)=(b-a)/\log(b/a)$ for $a \neq b$ and $L(a,a)=a$.

Eq. (12) shows that the index of CO₂ efficiency can be represented by the product of index of fuel structure, fuel efficiency and CO₂ emission factor with logarithmic weight function.⁹

⁸ According to Ang and Liu (2001), there are two types of weight functions for the log-mean Divisia index method. The method to be used in this study is the log-mean Divisia method I suggested by Ang and Liu (2001).

⁹ There are two forms of index decomposition equation; the multiplicative and additive forms. Eq. (12) is the multiplicative form where the index of an aggregate variable is represented by the multiplication of the index of compositional factors. In the additive decomposition equation, change of an aggregate variable is directly decomposed into the effect of each compositional factor. The additive form will be introduced later in this paper.

2.5. Compositional factors determining CO₂ emissions from car travel

The earlier Eq. (1) summarised the compositional factors determining the amount of CO₂ emission from car travel. According to this equation, an environmental Impact (the amount of CO₂ emissions from car travel) is represented by the product of three composition factors; Population, Affluence (car driving distance per person) and Technology (CO₂ emission per car driving distance) as the IPAT equation. This study then extended the decomposition equations to both affluence (A) factor and technology (T) factors. Eq. (1) can now be rewritten on the basis of the decomposition equations of Affluence and Technology factors.

First, by substituting with Eqs. (4) and (8), Eq. (1) can be rewritten into Eq. (13)

$$C = P \left(\frac{T_c}{P} \right) \left(\frac{D}{T_c} \right) \left[\sum_i \left(\frac{D_i}{D} \frac{F_i}{D_i} \frac{C_i}{F_i} \right) \right] \quad (13)$$

Eq. (13) again shows that the amount of CO₂ emissions from car travel is determined by population, car trip distance per person, occupancy rate, fuel efficiency, fuel structure and CO₂ intensity of fuel. We can reduce the amount of CO₂ emissions from car driving by reducing any of these factors.

Differentiating Eq. (13) with respect to the time and dividing by C leads to Eq. (14). Eq. (14) again reveals that the change rate in CO₂ emissions from car driving at a certain time point can be represented by the sum of change rate in each individual compositional factor; population, car trip distance per person, (reciprocal of) occupancy rate, fuel efficiency, fuel structure and CO₂ emission factor.

$$\begin{aligned} \frac{dC/dt}{C} = & \frac{1}{P} \frac{dP}{dt} + \frac{P}{T_c} \frac{d(T_c/P)}{dt} + \frac{T_c}{D} \frac{d(D/T_c)}{dt} \\ & + \sum_i \left(\frac{C_i}{C} \frac{D}{D_i} \frac{d(D_i/D)}{dt} \right) \\ & + \sum_i \left(\frac{C_i}{C} \frac{D_i}{F_i} \frac{d(F_i/D_i)}{dt} \right) \\ & + \sum_i \left(\frac{C_i}{C} \frac{F_i}{C_i} \frac{d(C_i/F_i)}{dt} \right) \end{aligned} \quad (14)$$

To quantitatively measure the relative contribution of each compositional factor on the change in CO₂

emission between year 0 and year T , Eqs. (5) and (12) is substituted into Eq. (3), resulting in Eq. (15).

$$\begin{aligned} \frac{C_T}{C_0} &= \frac{P_T}{P_0} \frac{(T/P)_T}{(T/P)_0} \frac{(D/T_c)_T}{(D/T_c)_0} \\ &\times \exp \left(\sum_i \frac{L(C_{i,0}/D_0, C_{i,T}/D_T)}{L(C_0/D_0, C_T/D_T)} \ln(s_{i,T}/s_{i,0}) \right) \\ &\times \exp \left(\sum_i \frac{L(C_{i,0}/D_0, C_{i,T}/D_T)}{L(C_0/D_0, C_T/D_T)} \ln(f_{i,T}/f_{i,0}) \right) \\ &\times \exp \left(\sum_i \frac{L(C_{i,0}/D_0, C_{i,T}/D_T)}{L(C_0/D_0, C_T/D_T)} \ln(c_{i,T}/c_{i,0}) \right) \end{aligned} \quad (15)$$

where $s_i = D_i/D$ (share of fuel type i in total vehicle km), $f_i = F_i/D_i$ (fuel efficiency of fuel type i) and $c_i = C_i/F_i$ (carbon intensity of fuel type i).

In Eq. (15), the index of CO₂ emissions from car travel was decomposed into the products of the index of each compositional factor. The decomposition of CO₂ efficiency of car driving (technology factor) in Eq. (15) was based on the multiplicative log-mean Divisia index method. However, there is an alternative way of decomposing an aggregate indicator. The total quantity of the changes in an aggregate indicator can be directly broken down into the changes in each compositional factor by using an additive index decomposition method. In particular, Ang et al. (1998) proposed the additive log-mean Divisia index decomposition method, which leaves no residual after decomposition. By applying the additive log-mean Divisia index decomposition method into Eq. (13), the total quantity of changes in CO₂ emissions can be distributed into the effect of individual compositional factor as in Eq. (16).

$$\begin{aligned} C_T - C_0 &= \sum_i [L(C_{i,0}, C_{i,T}) \ln(P_T/P_0)] \\ &+ \sum_i [L(C_{i,0}, C_{i,T}) \ln((T_c/P)_T/(T_c/P)_0)] \\ &+ \sum_i [L(C_{i,0}, C_{i,T}) \ln((D/T_c)_T/((D/T_c)_0))] \\ &+ \sum_i [L(C_{i,0}, C_{i,T}) \ln(s_{i,T}/s_{i,0})] \\ &+ \sum_i [L(C_{i,0}, C_{i,T}) \ln(f_{i,T}/f_{i,0})] \\ &+ \sum_i [L(C_{i,0}, C_{i,T}) \ln(c_{i,T}/c_{i,0})] \end{aligned} \quad (16)$$

where $s_i = D_i/D$ (share of fuel type i in total vehicle km), $f_i = F_i/D_i$ (fuel efficiency of fuel type i), $c_i = C_i/F_i$ (carbon intensity of fuel type i) and $L(a,b) = (b-a)/\log(b/a)$ for $a \neq b$ and $L(a,a) = a$.

Each term of the right hand of Eq. (16) represents the effect of each compositional factor in Eq. (13) on changes in CO₂ emission from car travel. Ang et al. (1998) provide the proof of perfect decomposition of the additive log-mean Divisia index method.

In this section, this study proposed various decomposition equations at difference levels of analysis, starting from the IPAT identity, to investigate the driving forces behind the changes in CO₂ emission from car travel. The following section will summarise the result of decomposition analysis based on these equations.

3. Decomposition analysis of changes in CO₂ emissions from car travel in Great Britain (1970–2000)

3.1. Data

Most of the figures in this paper are calculated by the author, based on data from Department for Transport (DfT), Transport Statistics Great Britain each year; Transport Trends 2001; Department of Trade and Industry (DTI), Digest of United Kingdom Energy Statistics each year; The Office for National Statistics (ONS), Annual Abstract of Statistics 2002 and internal data from DfT. The direct quote of data and other data sources will be indicated separately.

The data of fuel efficiency of car stocks in Great Britain need to be explained further. This study calculates fleet fuel efficiency by dividing total fuel (petrol and diesel) consumption by total car travelled distance. Transport Statistics Great Britain (DfT, each year) provides total fuel consumption data as well as the share of fuel use for car and taxi. DfT data is based on the total consumption in the UK and is measured by tonnes. It is converted to Great Britain basis by subtracting the consumption in Northern Ireland and converted to litres at the annual declared density in the Digest of UK Energy Statistics. However, the share of fuel use for car and taxi suggested by DfT does not seem to be precise in a detailed extent. Another factor difficult to estimate in calculating fleet fuel efficiency is to distribute total car km between petrol cars and diesel

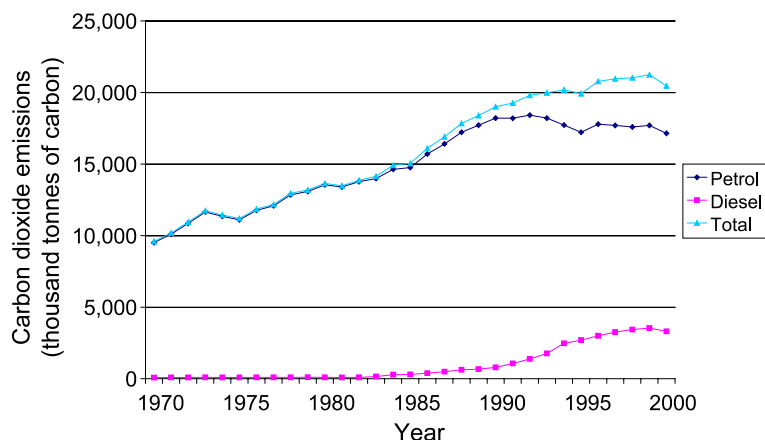


Fig. 2. Trend of carbon dioxide emission from car travel in Great Britain (1970–2000).

cars. This study distributed total car km into petrol cars and diesel car on the basis of total fuel consumption data and a supposed fuel efficiency of diesel cars compared to petrol cars. As the total fuel consumption data is regarded as a relatively precise figure (Rice, 1984), this calculation method is expected to provide a reasonable approximation of the long-term trend of fleet fuel efficiency. However, more cautious interpretation is required regarding the short-term changes in the trend.

3.2. Decomposition of changes in CO_2 emissions from car travel by the IPAT identity

CO_2 emissions from car travel increased from 9.6 million tonnes in equivalent carbon in 1970 to

20.5 million tonnes in equivalent carbon in 2000 (in Fig. 2), which is equivalent to an annual increase of 2.5%. As shown in the figure, diesel fuel share increased over time and the overall growth rate of emission seemed to slow down in recent years.

The above CO_2 emission trend can be broken down into population (P), affluence (A) and technology (T) factors by using Eq. (3) in Section 2.2. Fig. 3 shows the index of population (P), car driving distance per capita (D/P), and CO_2 intensity of car driving (C/D) over the last 30 years since 1970, the base year. As shown in the figure, most of the increase in CO_2 emission was caused by the increase in per capita car driving distance (the Affluence effect). CO_2

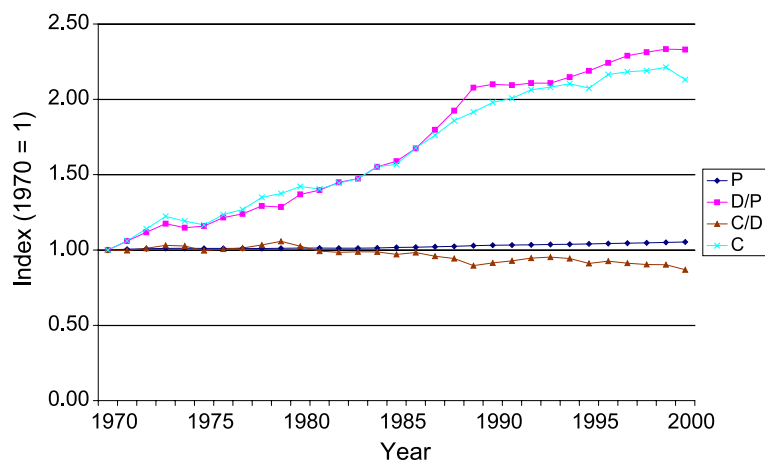


Fig. 3. Index of population (P), affluence (D/P) and technology (C/D) factors determining carbon dioxide emissions from car driving (C).

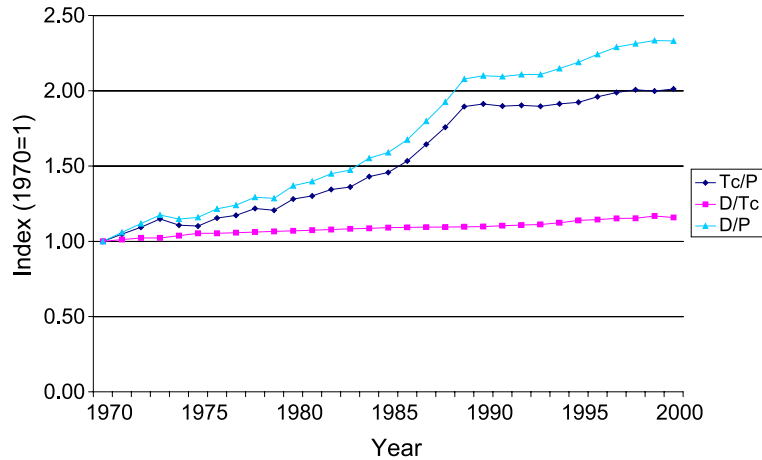


Fig. 4. Index of per capita car driving distance and its determinants.

emissions from car driving (C) and per capita car driving distance (D/P) shows very similar trends for most of the period although there is a slight gap between the two trends in the late 1980s and the late 1990s. CO_2 emissions from car travel increased more than twofold as mentioned earlier and per capita car driving distance also increased more than twofold from 2,865 km per year in 1970 to 6,677 km in 2000. Both of these two trends experienced slower growth rate in the 1990s than in the 1970s or 1980s.

Meanwhile the improvement of fuel efficiency or fuel substitution into less carbon intensive fuel led to the decrease of CO_2 emission per car driving distance (C/D) from 227 $\text{CO}_2\text{g/km}$ in 1970 to 197 $\text{CO}_2\text{g/km}$ in 2000—down by 13%. However, this technology (T) effect was relatively small when compared with the affluence (A) effect above. The improvement of CO_2 efficiency of car driving was most apparent in the late 1980s and the late 1990s. During this period, the technology effect partly cancelled out the affluence effect, preventing the rapid growth of CO_2 emissions from car travel. The change in population had the smallest impact on the growth of CO_2 emission from car travel among these three compositional factors.

In the next two sections, a more detailed decomposition analysis is made to investigate the key driving forces for the change in per capita car driving distance (D/P) and carbon intensity of car driving (C/D).

3.3. Decomposition of changes in per capita car driving distance

Based on Eq. (5) in Section 2.3, Fig. 4 shows the index of car driving distance per person and the two compositional factors determining its change over the last 30 years. As discussed earlier, per capita car driving distance (D/P) increased more than twofold over the last 30 years. The growth of per capita car trip distance (T_c/P) was a key factor for the change in per capita car driving distance. In 1970, people only travelled 5,227 km per year by car. This increased to 10,518 km by 2000—up by 101%. As shown in the graph, per capita car trip distance increased steadily in the 1970s and 1980s. In particular, it grew steeply in the late 1980s. However, it experienced a different pattern in the 1990s. After a slight decrease in the early 1990s, it started increasing again, but with a lower growth rate than in the 1970s and 1980s. Occupancy rate¹⁰ kept decreasing over the last 30 years, even during the 1990s. The average occupancy rate in 1970 was 1.82 but was only 1.58 in 2000. That explains why per capita car driving distance (D/P) kept increasing even in the 1990s when car trip

¹⁰ D/T_c in the figure denotes car driving distance (km) divided by car trip distance (person km), which is the reciprocal of occupancy rate. Thus the increase in D/T_c means the decrease in occupancy rate.

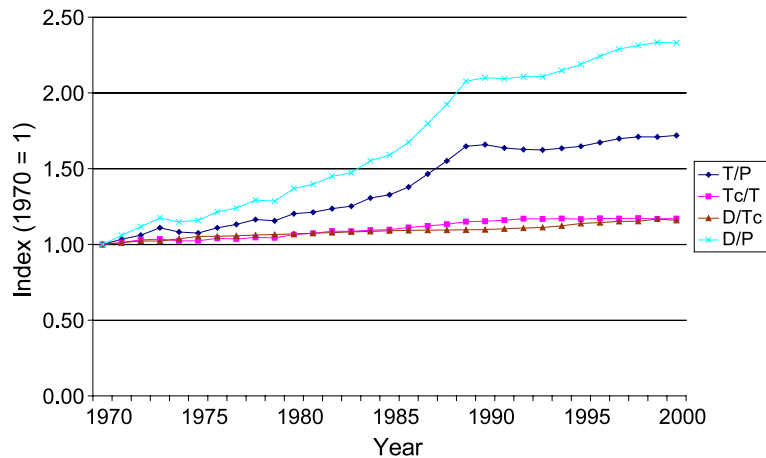


Fig. 5. Further break down of the index of per capita car driving distance.

distance per person (T_c/P) experienced only a marginal growth.

Fig. 5 disentangles T_c/P (car trip distance per person) in Fig. 4 into T/P (trip distance by all modes per person) and T_c/T (share of car trip in total trip distance), based on Eq. (6) in Section 2.3. Per capita trip distance by all modes (T/P) increased from 7,448 km per year in 1970 to 12,804 km in 2000—up by 72%. The share of car trip in total trip distance increased from 70% to 82% over the same period.

Fig. 6 presents the trends of per capita car trip distance and total trip distance by all modes. It clearly shows that total trip distance changed mostly due to the

changes in car trip distance. Trip distance by other modes remained nearly constant over the whole period.

As suggested earlier in Eq. (7), there is an alternative way of breaking down the determinants of changes in car driving distance per person (D/P) by focusing on changes in per capita vehicle (S/P) and average driving distance per vehicle (D/S). From this viewpoint, it can be seen that the growth of per capita car ownership was the dominant factor for the change in total car driving distances (in Fig. 7). During the last 30 years, the number of cars per thousand people increased from 184 in 1970 to 407 in 2000—up by 121%. During the same period, average driving

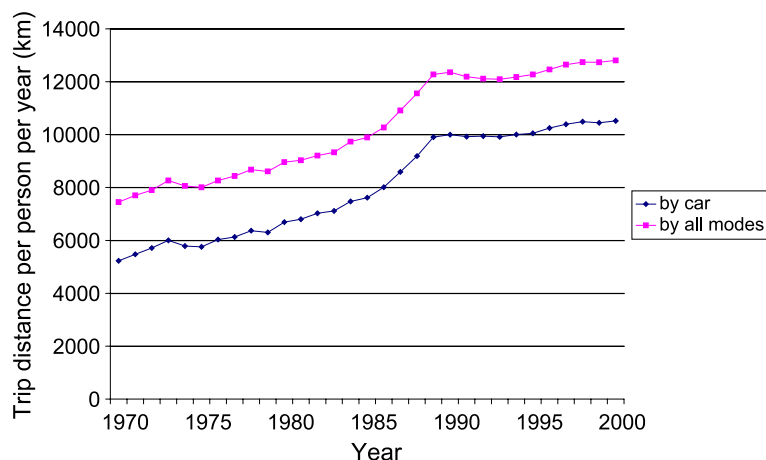


Fig. 6. Trends of per capita car trip distance and total trip distance by all modes.

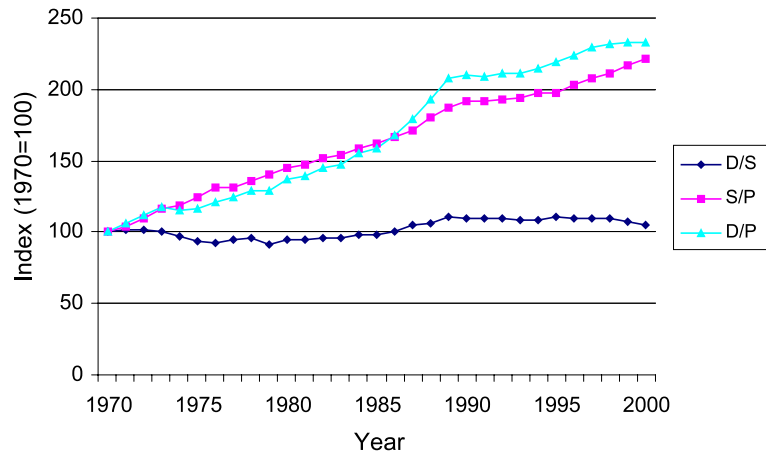


Fig. 7. Decomposition of car driving distance (D/P) by vehicle number (S/P) and vehicle uses (D/S).

distance per car remained relatively constant with the overall increase of less than 10%.

3.4. Decomposition of changes in CO_2 efficiency of car driving

It was found previously that CO_2 efficiency of car driving improved by about 13% between 1970 and 2000. CO_2 efficiency can improve by either enhancing fuel efficiency (fuel efficiency effect) or increasing the share of more CO_2 efficient fuel (fuel structure effect). Since no other alternative fuel except diesel and petrol has gained a significant market share in

Great Britain, fuel structure effect in this analysis only concern the change in market share of diesel.

The fleet fuel efficiency of petrol cars increased by about 13% over the last 30 years although it fluctuated continuously (see Fig. 8). In interpreting this estimation, however, a cautious approach is required because of data problems. More attention should be paid on the long-term trend rather than short-term changes in the trend. However, even considering the problem of data quality, there would be no doubt that the long-term increase in fuel efficiency partly compensated the effects caused by the growth of total car trip distances on CO_2 emissions. In fact, the 13% increase of fuel

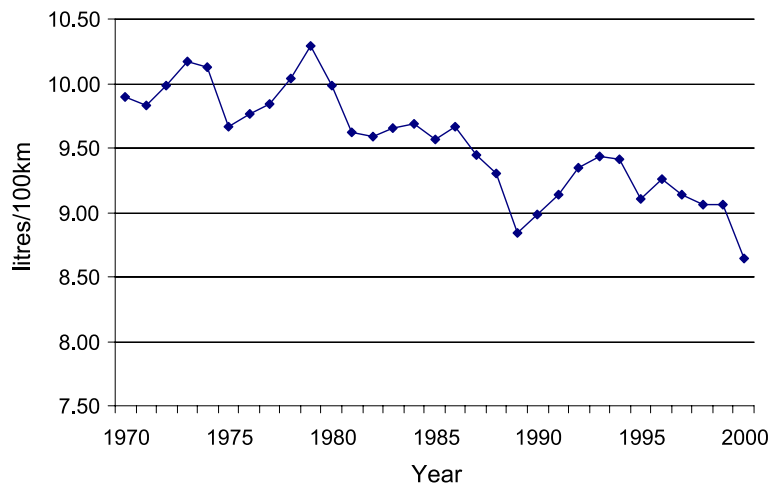


Fig. 8. Trend of fleet fuel efficiency (petrol).

efficiency over the 30 years, which is equivalent to the annual growth rate of 0.5% may be well below the expectation about fuel technology development. However, there are many other factors apart from fuel technology that determine change in fleet fuel efficiency. The detailed analysis of fuel efficiency factors will be attempted in a subsequent study.

Fig. 9 shows the result of decomposition analysis of changes in CO₂ efficiency of car driving by using the log-mean Divisia Index method introduced in Section 2.4 (Eq. (12)). It reveals that the increase in CO₂ efficiency over the last 30 years, which amounts to about a 13% improvement of CO₂ efficiency, was caused mostly by the improvement in fuel efficiency. The change of fuel structure had little impact during this period, only incurring a marginal effect. The diesel share in total vehicle km increased from 0.8% in 1970 to 17.7% in 2000. This change only made a small contribution in curbing increases in CO₂ emissions because diesel is only slightly more CO₂ efficient per driving distance than petrol.¹¹

3.5. Decomposition of changes in CO₂ emissions from car travel

Now the result of decomposition analysis of affluence (*A*) and technology factors (*T*) can be combined to provide a comprehensive view regarding the driving forces behind changes in CO₂ emissions from car travel in Great Britain over the last 30 years.

Eq. (15) in Section 2.5 provided a comprehensive decomposition equation of changes in CO₂ emissions from car travel. Fig. 10 shows the index based on Eq. (15). In fact, this graph is equivalent to the combination of Figs. 4 and 9). The affluence (*A*) factors such as car trip distance per person (*T/P*) and (a reciprocal)

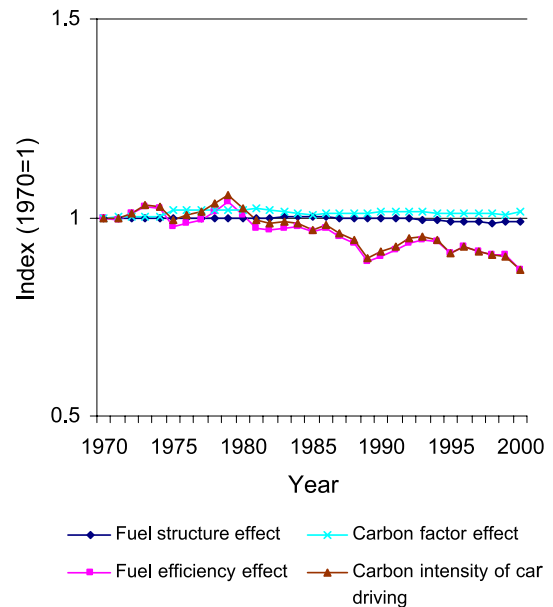


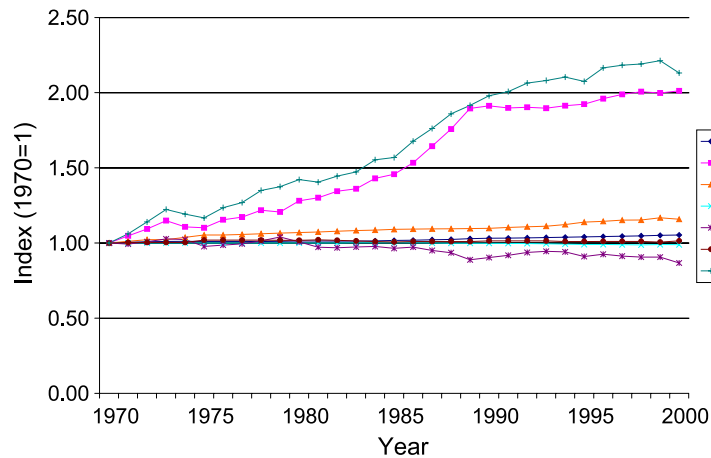
Fig. 9. Decomposition of changes in carbon intensity of car driving.

of occupancy rate (*D/T_c*) contributed to the increase of CO₂ emissions from car travel (*C*). In particular, the increase in car trip distance per person was a main driving force for the growth of CO₂ emissions from car travel until 1990. Meanwhile, the technology (*T*) factors such as fuel efficiency (*F_i/D_i*) and fuel structure (*D_i/D*) have managed to partly cancel out the affluence (*A*) effect. However, these effects were generally too small to cancel out the whole affluence effect.

This study also suggested an additive decomposition equation to break down changes in CO₂ emissions from car travel in Section 2.5. The total quantity of the changes in CO₂ emissions from car travel was directly broken down into the changes in each compositional factor by using the additive log-mean Divisia index decomposition method in Eq. (16). Fig. 11 summarises the result of the decomposition analysis based on Eq. (16). The estimation is split into the three periods (1970–1980, 1980–1990 and 1990–2000).

First, in the 1970s, CO₂ emissions from car travel increased from 9.6 million tonnes (in equivalent carbon) to 13.6 million tonnes—up by 42%. Of this change, 2.8 million tonnes (up by 30%) are estimated to have been caused by the increase in car trip distance per person, explaining 70% of the changes. Further,

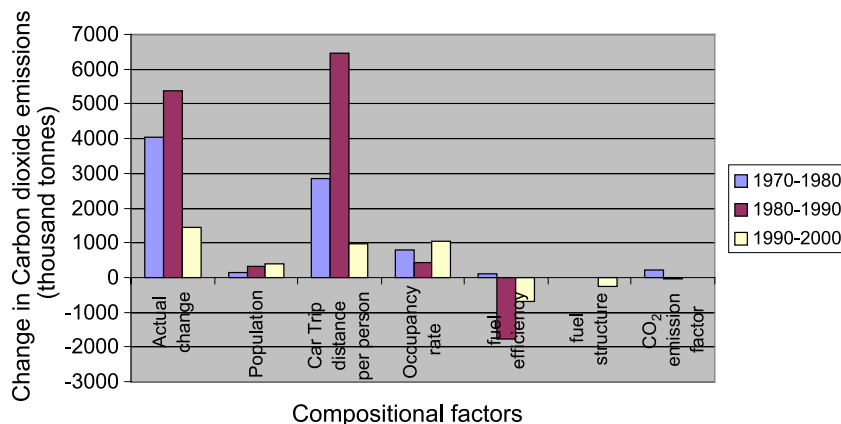
¹¹ The CO₂ factor of diesel fuel is higher than that of petrol by about 15% on a volumetric basis (kg C/l). However, since diesel fuel is generally more fuel efficient than petrol by about 20–50% (based on the calculation of average fuel consumption rate of each engine size class for the year 2001 new car models listed in New Car Fuel Consumption and Emissions Figure July 2001 of Vehicle Certification Agency (VCA)), overall it tends to be slightly more CO₂ efficient than petrol although the difference of fuel efficiency between diesel and petrol cars varies by model types. Of course, this should not be perceived that diesel fuel is more environmental friendly than petrol because diesel fuel is inferior to petrol in terms of many other pollutants.

Fig. 10. Decomposition of trend in CO₂ emission from car travel.

the decrease of occupancy rate led to the increase of emissions by 0.8 million tonnes (up by 8%), equivalent to 19% of the changes. The technology factors such as fuel efficiency or fuel structure had only marginal impacts in 1970s.

Then, in the 1980s, CO₂ emissions increased by 5.4 million tonnes—up by 39%. Again the increase in car trip distance per person was the most dominant driving force in this period. It is estimated that the change in car trip distance per person alone led to the increase of emissions of 6.5 million tonnes—up by 47%. Among the technology (*T*) factors, the improvement of fuel efficiency managed to partly offset the effect of the affluence (*A*) factors. The fuel efficiency effect is estimated to have decreased CO₂ emissions by 1.8 million tonnes—down by 13%.

Meanwhile, since the early 1990s, the growth of CO₂ emissions from car travel started to slow down. Emissions only increased by 1.5 million tonnes—up by 7.6%. The most important driving force in this period was the decrease in occupancy rates. Average occupancy rates fell from 1.66 in 1990 to 1.58 in 2000. This is estimated to have increased CO₂ emissions by 1.4 million tonnes—up by 5.5%, explaining 72% of overall increases over the 1990s. The population (*P*) growth in the 1990s also contributed to more of an increase in CO₂ emissions than in the previous two decades. However, car trip distance per person showed relatively little growth in this period unlike in the previous two periods. It led to the increase of emissions by only 1 million tonnes—up by 5.2%. Regarding technology (*T*) factors, the

Fig. 11. The result of additive log-mean Divisia index decomposition of changes in CO₂ emissions from car driving.

fuel efficiency and fuel structure effects contributed to the reduction of emissions by 3.7% and 1.4%, respectively. Fuel structure effects in 1990s were more significant than in the two previous periods due to the increase of the diesel market share.

4. Conclusion

As summarised in the IPAT equation, the degree of the Impact of human activity on the environment is determined by changes in Population, Affluence (per-capita consumption) and Technology (environmental impact per quantity of consumption). The IPAT equation is a useful starting point to trace back causal chains determining the trends of an environmental indicator. This paper broke down determinants of growth in CO₂ emissions from car travel by using various decomposition analyses, starting from the $I=PAT$ equation.

Affluence (A), which represents car driving distance per person in this case, was a dominant force for the growth of emissions over the last 30 years. Not only do people travel longer distances by cars than 30 years ago, car occupancy rates have also decreased, contributing to the growth of car driving distance per person. Although technology (T) factors such as fuel efficiency and fuel substitution to diesel fuel partly cancelled out the growth effects of the affluence (A) factors, this contribution was relatively small. However, in the 1990s there emerged a different pattern in the trend. Of the affluence (A) factors, the growth rate of car trip distance per person weakened considerably. As for the technology (T) effect, the carbon intensity of car driving kept decreasing over this period. Therefore, although CO₂ emissions from car travel (I) continued to increase, the growth rate became substantially lower than in the earlier periods.

This study alone cannot confirm whether the trend in 1990s indicates that carbon dioxide emission from car travel in Great Britain reached the turning point of the Environmental Kuznets Curve¹², or it is still in a

growing tendency. More detailed investigation is needed into the determinants of both affluence (A) factors and technology (T) factors, respectively. These are the tasks of subsequent studies by the author.

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¹² According to the so-called ‘Environmental Kuznets Curve’ (EKC) hypothesis, the relationship between income and environmental degradation is described as an inverted U curve. The overall review of EKC hypothesis can be referred to in Stern (1998), Rothman and de Bruyn (1998) and Borghesi (2002).

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